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Review

Sorption thermal storage for solar energy

N. Yu, R.Z. Wang*, L.W. Wang

Institute of Refrigeration and Cryogenics, Shanghai Jiao Tong University, Shanghai 200240, China

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ABSTRACT

Sorption technologies, which are considered mainly for solar cooling and heat pumping before, have gained a lot of interests for heat storage of solar energy in recent years, due to their high energy densities and long-term preservation ability for thermal energy. The aim of this review is to provide an insight into the basic knowledge and the current state of the art of research on sorption thermal storage technologies. The first section is concerned with the terminology and classification for sorption processes to give a clear scope of discussion in this paper. Sorption thermal storage is suggested to cover four technologies: liquid absorption, solid adsorption, chemical reaction and composite materials. Then the storage mechanisms and descriptions of basic closed and open cycles are given. The progress of sorption materials, cycles, and systems are also reviewed. Besides the well-known sorbents like silica gels and zeolites, some new materials, including aluminophosphates (AlPOs), silico-aluminophosphates (SAPOs) and metal-organic frameworks (MOFs), are proposed for heat storage. As energy density is a key criterion, emphais is given to the comparison of storage densities and charging tempertures for different materials. Ongoing research and development studies show that the challenges of the technology focus on the aspects of different types of sorption materials, the configurations of absorption cycles and advanced adsorption reactors. Booming progress illustrates that sorption thermal storage is a realistic and sustainable option for storing solar energy, especially for long-term applications. To bring the sorption storage solution into market, more intensive studies in fields of evaluation of advanced materials and development of efficient and compact prototypes are still required.

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* Corresponding author. Tel./fax: +86 21 34206548.
E-mail address: rzwang@sjtu.edu.cn (R.Z. Wang).

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1. Introduction

With the depletion of fossil fuels and the challenge of global warming, the world community has taken initiatives to steer energy sources toward renewable energy. Solar energy is regarded as one of the most promising substitutes for traditional energy resources; however, its intermittent and unstable nature is a major drawback, which leads to a disparity between supply and demand. Energy storage is an appropriate method of correcting the disparity [1]. To enhance the fraction of energy utilization and make solar energy products more practical and attractive, thermal storage systems today are perceived as crucial components in solar energy applications.

Methods of solar thermal energy storage are mainly divided into three types: sensible, latent and thermochemical [2]. Sensible and latent thermal storage are the most studied technologies in recent decades. Most thermal storage devices applied in practical solar driven systems employ sensible and latent storage methods. For sensible storage, heat is stored by the temperature difference of the storage medium; the value of its storage density closely depends on the product of its specific heat and the temperature difference. Water, brick, rock and soil are the most common materials in sensible energy storage applications.

In the latent thermal storage method, heat is stored through the phase change process of a material at a constant temperature. The materials are often referred to as Phase Change Materials (PCMs). These storage substances are generally ice, paraffin, fatty acids, salts and other mixtures [3]. Compared with sensible thermal storage, latent heat has greater storage density with a much smaller temperature interval; but it still involves many drawbacks, such as long-term stability of storage properties, low thermal conductivity, phase segregation and subcooling during the phase change process [4].

Thermochemical storage can be divided into chemical reaction (should be called “chemical reaction without sorption” strictly) and sorption [2]. Large amounts of heat can be stored in reversible chemical reactions and sorption processes. In a sorption process, heat is stored by breaking the binding force between the sorbent and the sorbate in terms of chemical potential. The features of sorption thermal storage method are illustrated as follows:

- Desorption (charging) process requires the supply of heat to expel the sorbate from the restriction of the sorbent. The heat required is higher than that associated with the evaporation (or condensation) heat of pure sorbate (such as water). Large integral heat of desorption involved in the desorption (or sorption) process causes high energy densities of sorption materials, in theory, only next to chemical reaction (see Fig. 1). Thus a smaller volume is needed for a given storage capacity for sorption thermal storage, according to Hadorn [2], only one-third of that required for sensible heat storage system with water.
- A sorption process will not occur until the sorbent contacts with the sorbate, so the binding energy can be stored, independent of the time span between the desorption process and the sorption process. Thus, sorption storage is also called an “indirect” thermal storage approach from the view of thermodynamics, distinguished from other “direct” sensible and latent methods [5]. The heat and entropy is not stored in the storage vessels but released to the environment for the indirect storage. This feature makes sorption thermal storage a promising solution for long-term solar energy storage applications, where solar energy is stored in summer to meet heating demands in winter [6].
- Conventional heat storage materials, such as PCMs, can only be applied at specific temperature levels as their phase transition temperatures are definite, which imposes restrictions on the temperature ranges of their applications. However, input and output temperature levels of a sorption thermal storage system are determined by practical demands and working conditions. The discharging process could be operated to provide cooling effect from the evaporator in summer or heating effect from the reactor in winter, exhibiting some extent of flexibility.

Although sorption thermal storage systems offer some benefits, there are still critical drawbacks, such as great complexity in the system configuration (for closed systems), expensive investment, poor heat and mass transfer ability (for chemical reaction) and low heat storage density in actual systems. To overcome these barriers, extensive academic efforts are now being carried out worldwide. The past and present studies on sorption thermal storage are mainly related to the search and evaluation of sorption storage materials [7–11], proposal of sorption cycles [12–21], and development of reactors [22,23]. This review presents the state of the art of sorption thermal storage technology for solar energy, including terminology of some basic terms and concepts, fundamentals, energy densities of diverse sorbents in varied temperature ranges, progress in different configurations of liquid absorption cycles, and new concepts concerning the design of reactors in solid adsorption systems. Some of the typical past and present projects for both short-term and long-term applications are presented. These cases could be served as important references for future endeavors. Major conclusions and perspectives are pointed out at the end of this review.